Trends in use of off-pump coronary artery bypass grafting: Results from the Society of Thoracic Surgeons Adult Cardiac Surgery Database

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Objectives: Recent national trends in off-pump versus on-pump coronary artery bypass grafting have not been reported.

Methods: We analyzed data from the Society of Thoracic Surgeons Adult Cardiac Surgery Database regarding isolated primary coronary artery bypass grafting operations (N = 2,137,841; 1997-2012). The off-pump percentages were calculated in aggregate, by center, and by surgeon. On the basis of the 2007/2008 yearly off-pump volume, the analysis subgroups were "high" (center n > 200, surgeon n > 100), "intermediate" (center n = 50-200, surgeon n = 20-100), and "low" (center n = 1-49, surgeon n = 1-19).

Results: The use of off-pump procedures peaked in 2002 (23%) and again in 2008 (21%), followed by a progressive decline in off-pump frequency to 17% by 2012. After 2008, off-pump rates declined among both high-volume and intermediate-volume centers and surgeons; little change was observed for low-volume centers or surgeons (off-pump rates = 10% since 2008). By the end of the study period, 84% of centers performed fewer than 50 off-pump cases per year, 34% of surgeons performed no off-pump operations, and 86% of surgeons performed fewer than 20 off-pump cases per year. Except for a higher (7.8%) conversion rate in 2003, the rate for conversions fluctuated approximately 6%.

Conclusions: Enthusiasm for off-pump coronary artery bypass grafting has been tempered. The percentage of coronary artery bypass grafting operations performed off-pump has steadily declined over the last 5 years, and currently this technique is used in fewer than 1 in 5 patients who undergo surgical coronary revascularization. A minority of surgeons and centers continue to perform off-pump coronary artery bypass grafting in most of their patients. (J Thorac Cardiovasc Surg 2014;148:856-64)

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Supplemental material is available online.

Off-pump (OFF) coronary artery bypass grafting (CABG) was introduced in the early 1990s and gained popularity over the next decade as a potential means of avoiding several of the complications and adverse effects of cardiopulmonary bypass (CPB), such as thrombocytopenia, activation of complement factors and inflammatory responses, and immunosuppression.[1] The avoidance of aortic cannulation with the OFF approach was likewise predicted to decrease the incidence of stroke and other embolic phenomena compared with procedures performed with CPB. However, although some studies have associated OFF CABG with favorable outcomes,[2-6] others have not found a significant benefit to OFF CABG.[7-12]

In 2007, an intent-to-treat comparison of risk-adjusted outcomes was made between patients undergoing OFF CABG and patients undergoing on-pump (ON) CABG who were treated at experienced centers that contribute to the Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS ACSD).[13] This comparison showed a significant advantage for OFF CABG with regard to mortality and numerous morbidity end points. The relative benefit of OFF was greatest in patients with the most preoperative risk factors. Shortly after those findings were reported, results of the VA Outcomes Following Myocardial Revascularization:

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Disclosures: Authors have nothing to disclose with regard to commercial support.

Read at the 94th Annual Meeting of The American Association for Thoracic Surgery, Toronto, Ontario, Canada, April 26-30, 2014.

The opinions expressed are those of the authors and not necessarily those of the Society of Thoracic Surgeons.

Received for publication Sept 3, 2013; revisions received Oct 28, 2013; accepted for publication Dec 4, 2013; available ahead of print July 17, 2014.

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0022-5223/$0.00

Published by Elsevier Inc. on behalf of The American Association for Thoracic Surgery

http://dx.doi.org/10.1016/j.jtcvs.2013.12.047

Abbreviations and Acronyms

CABG = coronary artery bypass grafting
CPB = cardiopulmonary bypass
OFF = off-pump
ON = on-pump
STS ACSD = Society of Thoracic Surgeons Adult Cardiac Surgery Database

On and Off Cardiopulmonary Bypass trial were published, showing no significant difference between treatment groups in the rate of the 30-day composite outcome of death or complications.[14] However, of notable concern was a lower patency rate of bypass grafts and less effective revascularization in the OFF cohort in the first postoperative year.

Given the inconsistency in the literature as to the relative benefits of OFF and ON CABG, it would be of interest to know the extent to which OFF CABG has been widely accepted by cardiac surgery practices nationwide and the degree to which the use of OFF CABG has changed over time. In addition, the difference in the risk profiles of patients who undergo surgical revascularization by either of these 2 approaches has not been well characterized.

The specific objective of this STS ACSD research project was to use time-dependent analyses to test for national trends in the use rates of OFF versus ON CABG, and for volume-specific trends among centers and surgeons. In addition, we examined the differences in the risk profiles of patients who undergo OFF versus ON CABG.

MATERIALS AND METHODS

Patient Population

The study cohort consisted of all patients aged more than 18 years who underwent primary isolated CABG between January 1, 1997, and September 30, 2012, at any hospital that participated in the STS ACSD. Patients who underwent emergency CABG, robotic-assisted procedures, reoperative CABG, or any concomitant cardiac operation were excluded. Figure 1 summarizes the study design, including the time-based cohorts and the volume subgroups for centers and surgeons analyzed.

Data Elements

The STS ACSD is a clinical registry widely used to assess changes in patient risk characteristics, clinical practice patterns, and outcome rates. During the study period, STS data definitions and elements changed. For the present study, 5 versions of the STS data-collection form were used: version 2.35 for 1997 to 2002, version 2.41 for 2002 to 2004, version 2.52 for 2004 to 2007, version 2.61 for 2008 to 2011, and version 2.73 for 2011 to 2012. Two versions were in use simultaneously during parts of 2002, 2004, 2007, and 2011. Information about these versions of the STS database can be found on the STS Web site (available at: http://www.sts.org/quality-research-patient-safety/national-database/database-managers/adult-cardiac-surgery-database/d). All definitions were reviewed to determine whether the study variables had comparable definitions over time. Variables that changed substantially were excluded from the analysis. Variables that had minor definitional changes or for which data were collected during only part of the study period (ie, at least 8 years during which the definitions were consistent) were included in this analysis.

Outcome Measures

The study's primary outcome measure was the percentage of OFF versus ON procedures as a function of time. Because some of the rate changes may have been due to the changing population (the number of sites participating in the database more than doubled from 1997 to 2012), a sensitivity analysis of the overall trends was performed on data from the subgroup of sites (n = 193) that submitted data for the whole 1997-2012 time period.

To specifically focus on recent trends in OFF use, the monthly percentage of OFF procedures was calculated from January 2008 to September 2012. In addition, for that period, we looked at the impact of volume on use trends by stratifying centers and surgeons according to their 2007/2008 yearly OFF caseload: (1) "high" volume centers (n > 200) or surgeons (n > 100), (2) "intermediate" volume centers (n = 50-200) or surgeons (n = 20-100), and "low" volume centers (n = 1-49) or surgeons (n = 1-19). For the volume-stratified analysis, we included only the 967 sites that submitted data for the full time period from 2007/2008 onward and the 2480 surgeons who submitted data for the full study period.

Data regarding intraoperative conversion from OFF to ON were captured starting in 2002, and unplanned conversions were captured starting in 2004. A planned conversion was defined as any scenario in which the surgeon's intention was to use or possibly use CPB for at least part of the procedure, whereas an unplanned conversion was defined as the use of CPB in cases in which the surgeon had originally intended not to. "As-treated" analysis was used for use trends analyses that spanned the entire study period, and "intention-to-treat" analysis was used for surgeon- and center-level trend analyses of data collected after 2008 (Figure 1).

For the comparison of patient characteristics, the STS ACSD data collected from 2002 onward were used for an intention-to-treat analysis, in which conversion-related adjustments were performed.

Statistical Analysis

This research study's analyses were coordinated by the STS Access and Publications Work Group; all statistical analyses were performed by the Duke Clinical Research Institute and STS National Research Office team members. Descriptive statistics were used to report patient characteristics in aggregate and by center and surgeon. Differences in OFF versus ON patient characteristics were assessed with the chi-square test for categoric variables and the Wilcoxon rank-sum test for continuous variables. Time-dependent trends were evaluated by using a 1-sided Cochran–Armitage test for a decreasing trend against the null hypothesis that the proportion of OFF CABG cases is the same for all years. Given the large sample size used, almost all comparisons documented a statistically significant finding; thus, clinically relevant differences also were evaluated.

RESULTS

Relative Use of ON Versus OFF Coronary Artery Bypass Grafting for Entire Cohort (1997-2012)

The relative use of OFF CABG peaked at 23% in 2002. This peak was followed by a slow decline to 19% in 2006, a secondary peak of 21% in 2008, and then a decline to 17% in 2012 (Figure 2).

Subgroup A, Centers That Submitted Data for the Entire Study Period (1997-2012)

The ON and OFF rates among the subset of sites (n = 193) that reported for the entire study period were similar to those of the overall cohort, although these sites had a slightly greater decline in OFF procedures between 2002 and 2006 and between 2008 and 2012 (Figure E1).

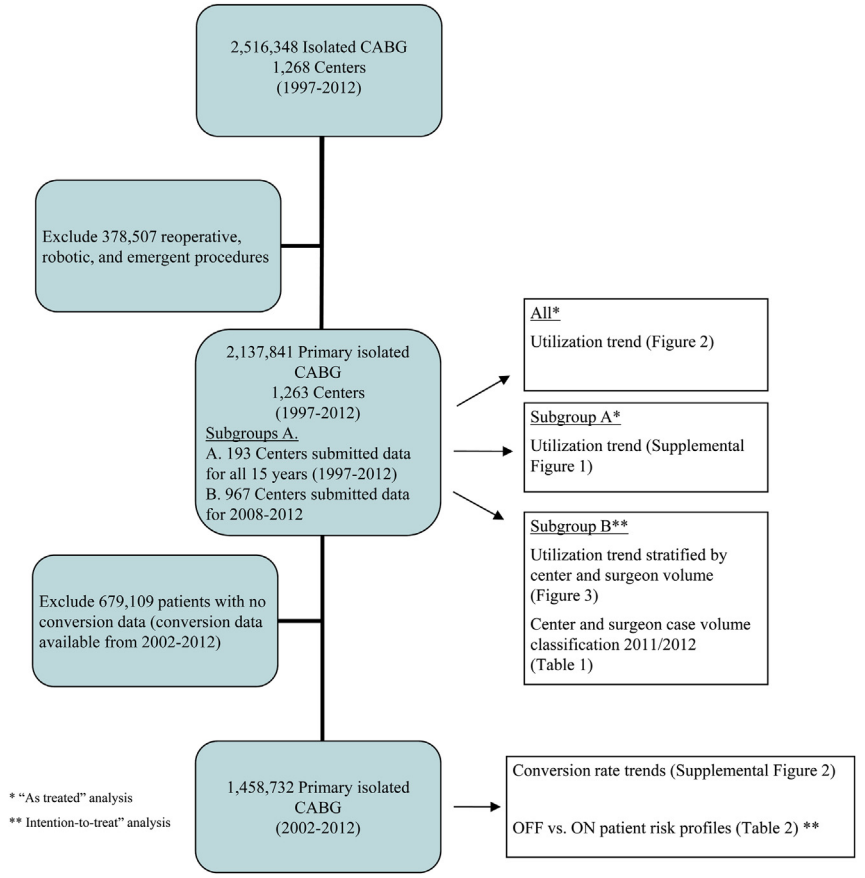

FIGURE 1. Summary of study design and analysis. *CABG*, Coronary artery bypass grafting.

Subgroup B, Centers That Submitted Data for Recent Era-Trend Analysis Period (2008-2012)

The decrease in OFF use after 2008 was mostly driven by a gradual decline in use by high- and intermediate-volume centers and surgeons (Figure 3). The high- and intermediate-volume centers and surgeons accounted for only 15% and 14% of the reporting centers and surgeons, respectively (Table 1). Throughout the study period, there

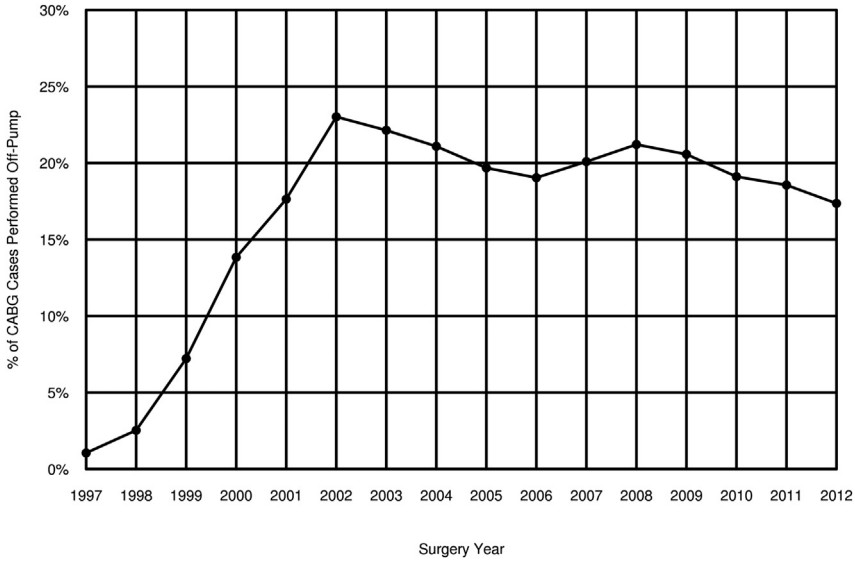

FIGURE 2. Relative use of ON versus OFF CABG for the entire cohort (1997-2012). *CABG*, Coronary artery bypass grafting.

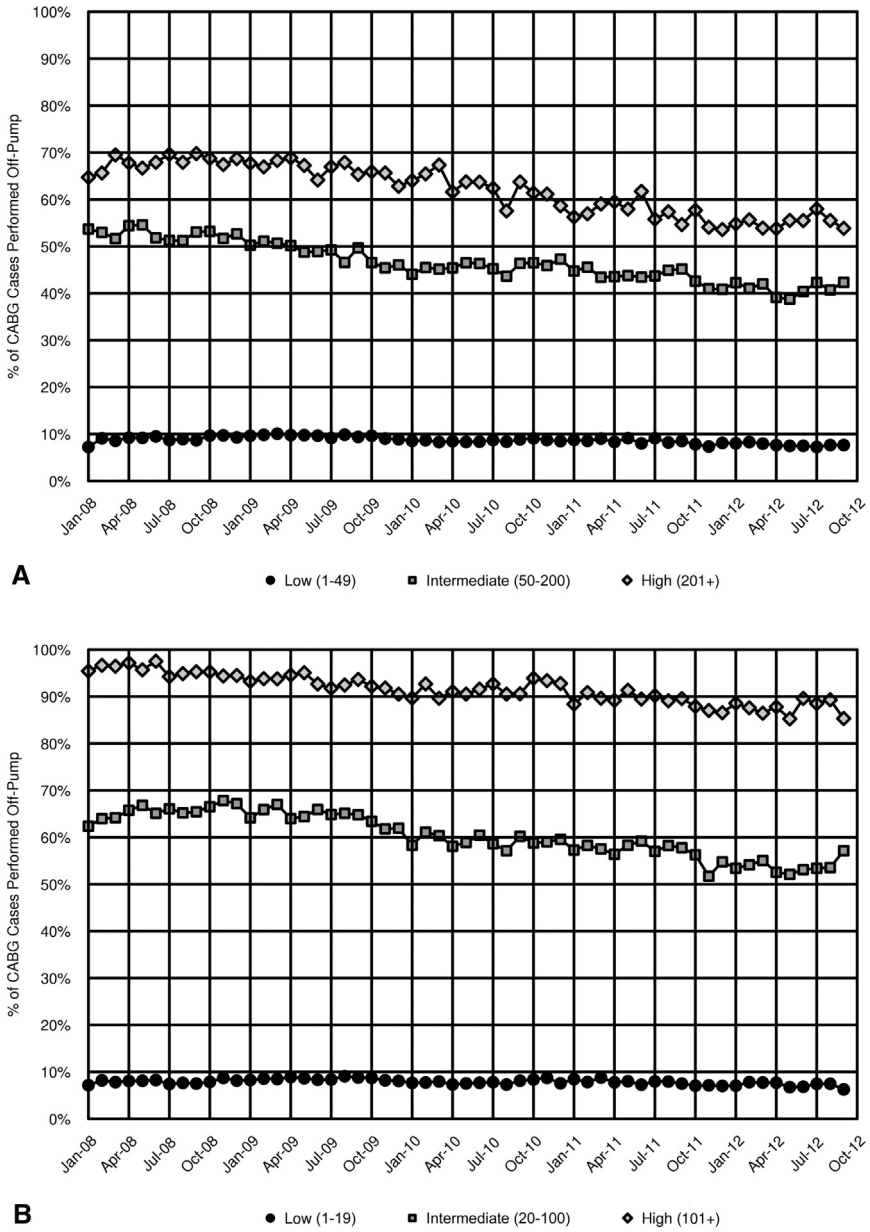

FIGURE 3. OFF use trends stratified by (A) center volume and (B) surgeon volume. *CABG*, Coronary artery bypass grafting.

was a small decline in the use of OFF CABG by low-volume centers and surgeons.

By the end of the study period (2011/2012), 84% of centers performed fewer than 50 OFF cases per year. Likewise, 86% of surgeons performed fewer than 20 OFF operations per year, and 34% of surgeons performed no OFF cases. The median number of OFF cases per year was 6.3 (interquartile range, 1.7-26.8) for centers and 1.7 for surgeons (interquartile range, 0-7.6) (Table 1).

Conversion Rate Trends (2002-2012)

For all conversions (Figure E2), except for a higher (7.8%) conversion rate in 2003, the aggregate rate for conversions averaged 6%. For unplanned conversions, the rate was 1.1% in 2004 and increased to 2.6% in 2005; then, slowly but somewhat consistently, this rate increased to 3.3% in 2012.

In a subgroup analysis of the conversion rates at centers that submitted data from the recent era (2008-2012), conversion rates were lower at higher-volume OFF centers (7.3% [low] vs 6.0% [intermediate] vs 3.6% [high]) and surgeons (8.4% [low] vs 6.3% [intermediate] vs 2.6% [high]) ($P < .0001$ for both comparisons).

ON Versus OFF Patient Characteristics (2002-2012)

Compared with ON approaches, OFF was used more frequently in female patients (29.5% vs 26.6%) (Table 2).

TABLE 1. Distribution of OFF case volume (2011/2012)

Category	Value*
Center OFF volume (per y)	N = 1056
None	130 (12)
Low (1-49 cases)	765 (72)
Intermediate (50-200 cases)	150 (14)
High (>200 cases)	11 (1)
Overall	
Mean OFF cases/center/y	24.4 ± 44.0
Median OFF cases/center/y	6.3 (IQR, 1.7-26.8)
Surgeon OFF volume (per y)	N = 2626
None	879 (34)
Low (1-19 cases)	1367 (52)
Intermediate (20-100 cases)	342 (13)
High (>100 cases)	38 (1)
Overall	
Mean OFF cases/surgeon/y	10.4 ± 23.2
Median OFF cases/surgeon/y	1.7 (IQR, 0-7.6)

IQR, Interquartile range; *OFF*, off-pump. *Values are number (%), mean ± standard deviation, or median (IQR).

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Patients in the OFF group were approximately 1 year older (median age, 66.0 vs 65.0 years). Among the numerous differences in the risk profiles of the ON and OFF groups, there was a higher prevalence of diabetes, left main disease, 3-vessel disease, unstable angina, intra-aortic balloon pump use, and urgent procedures in the ON group ($P < .001$, for all), although in most instances the absolute differences were small (Table 1). The predicted risk of mortality or morbidity was significantly higher for the OFF group (13.3% vs 13.1%, $P < .001$), probably as a result of a higher prevalence of noncardiac comorbidities. However, this difference is almost negligible from a practical perspective.

DISCUSSION

This is the first comprehensive review of national trends in OFF versus ON CABG use in the United States. The use of OFF CABG peaked in 2003, when slightly less than one quarter of all isolated CABG cases were performed without CPB (Figure 2). Since then, the proportion of OFF CABG has gradually declined. This finding is consistent with an earlier report on the trends of use of OFF CABG in the Veterans Affairs health system.[15] The reasons for this decline are speculative but may be partly related to both individual center and surgeon dissatisfaction with the procedure and the results of clinical trials. A recent Cochrane pooled analysis[11] of data from more than 80 trials of ON and OFF CABG showed superior short and mid-term outcomes with the ON approach.

The largest randomized trial to date, the CABG Off or On Pump Revascularization study, found no significant difference at 30 days or 12 months in the rate of a primary composite outcome of death, myocardial infarction, stroke, or new renal failure necessitating dialysis between patients who underwent OFF CABG and patients who underwent ON CABG.[16,17] The German Off-Pump Coronary Artery Bypass Grafting in Elderly Patients study looked at the same composite primary end point, focusing exclusively on patients aged 75 years or more, and reported similar findings.[18]

Notwithstanding these declining use trends and the results of trials, the potential advantages of OFF CABG have been documented by 3 large observational studies, which have associated OFF CABG with reduced in-hospital mortality.[13,19,20] The previously mentioned STS ACSD study[13] focused on centers that perform more than 50 OFF cases per year; evidence suggests that programs with greater OFF CABG experience may have better results than programs that perform these procedures less frequently.[21] However, in the aforementioned CABG Off or On Pump Revascularization trial,[16,17] surgeons had more than 2 years of experience and had performed more than 100 OFF cases. Although there was no significant difference in the composite primary end point between the ON and OFF groups, the use of OFF CABG, compared with ON CABG, significantly reduced the rates of reoperation for perioperative bleeding, acute kidney injury, and respiratory complications but increased the rate of revascularization.[16,17] Likewise, the selection of experienced OFF surgeons in the German Off-Pump Coronary Artery Bypass Grafting in Elderly Patients study did not translate into better OFF outcomes.[18]

In our study, patients in the OFF group had a higher incidence of noncardiac comorbidities, but patients in the ON group had a higher prevalence of cardiac acuity and more complex coronary artery disease (Table 2). Intuitively, the benefits of OFF CABG may be more apparent in high-risk patients, especially those with chronic obstructive pulmonary disease, renal or hepatic insufficiency, and advanced atheromatous disease of the ascending aorta. However, the evidence for the advantage of OFF CABG in those scenarios is primarily derived from retrospective studies.[22-25]

The advantages of OFF CABG reported by some experienced operators and centers may have not been realized in many of the published trials because of their enrollment of predominantly low-risk patients. Furthermore, clinical trials and observational studies that involve a broad spectrum of programs, including those with both high and low OFF CABG volumes, may be less likely to show major advantages for OFF CABG than studies by surgeons who perform these procedures preferentially and almost exclusively.[26] Hospital organizational structure is probably another important consideration that can influence outcomes and that is not typically captured or reported in trials.[27]

From our volume data (Table 1), it is apparent that most surgeons can be considered ‘‘occasional’’ OFF surgeons

TABLE 2. Risk profile

Variable	Overall (N = 1,458,732)		ON CABG (n = 1,143,003)		OFF CABG (n = 315,729)		
	Value	Missing	Value	Missing	Value	Missing	*P* value*
Demographics							
Age, y	65 (57-73)	0	65 (57-73)	0	66 (58-74)	0	<.0001
Gender, male	1,061,807 (72.79)	234	839,152 (73.42)	176	222,655 (70.52)	58	<.0001
Race, Caucasian	1,247,714 (85.53)	6303	980,198 (85.76)	5117	267,516 (84.73)	1186	<.0001
Risk factors							
STS predicted morbidity/ mortality (2007 model)	10.22 (7.09-15.89)	234	10.24 (7.15-15.82)	176	10.18 (6.90-16.20)	58	<.0001
History of chronic lung disease		6188		5111		1077	<.0001
None	1,136,986 (77.94)		891,658 (78.01)		245,328 (77.70)		
Mild	176,429 (12.09)		138,739 (12.14)		37,690 (11.94)		
Moderate	89,623 (6.14)		69,894 (6.11)		19,729 (6.25)		
Severe	49,506 (3.39)		37,601 (3.29)		11,905 (3.77)		
Current or recent smoker	381,846 (26.18)	2826	302,855 (26.50)	2249	78,991 (25.02)	577	<.0001
History of congestive heart failure	204,479 (14.02)	987	159,774 (13.98)	687	44,705 (14.16)	300	.0078
History of cerebrovascular disease	200,927 (13.77)	543	154,406 (13.51)	420	46,521 (14.73)	123	<.0001
History of stroke	101,269 (6.94)	1911	77,585 (6.79)	1572	23,684 (7.50)	339	<.0001
History of diabetes mellitus	574,367 (39.37)	407	455,750 (39.87)	301	118,617 (37.57)	106	<.0001
History of hypertension	1,202,147 (82.41)	334	943,066 (82.51)	239	259,081 (82.06)	95	<.0001
History of dyslipidemia	1,163,119 (79.73)	1637	914,250 (79.99)	1383	248,869 (78.82)	254	<.0001
Previous MI	639,178 (43.82)	1219	506,134 (44.28)	861	133,044 (42.14)	358	<.0001
History of peripheral vascular disease	215,824 (14.80)	744	165,952 (14.52)	573	49,872 (15.80)	171	<.0001
Current renal failure necessitating dialysis	30,443 (2.09)	2806	22,789 (1.99)	2443	7654 (2.42)	363	<.0001
NYHA class III or IV	514,273 (35.25)	5191	402,293 (35.20)	3889	111,980 (35.47)	1302	.002
Angina	1,219,193 (83.58)	4325	957,645 (83.78)	3495	261,548 (82.84)	830	<.0001
Unstable angina	721,782 (49.48)	4325	570,187 (49.88)	3495	151,595 (48.01)	830	<.0001
Last creatinine level preoperatively	1 (0.90-1.20)	8131	1 (0.90-1.20)	6253	1 (0.90-1.20)	1878	<.0001
Ejection fraction	55 (45-60)	55,972	55 (45-60)	42,527	55 (45-60)	13,445	<.0001
No. of diseased vessels	3 (3-3)	2706	3 (3-3)	1893	3 (2-3)	813	<.0001
Left main coronary disease (≥50% stenosis)	428,229 (29.36)	3561	340,881 (29.82)	2830	87,348 (27.67)	731	<.0001
Preoperative IABP	74,470 (5.11)	2429	60,138 (5.26)	1815	14,332 (4.54)	614	<.0001
Status of procedure		0		0		0	<.0001
Elective	687,399 (47.12)		531,040 (46.46)		156,359 (49.52)		
Urgent	771,333 (52.88)		611,963 (53.54)		159,370 (50.48)		

CABG, Coronary artery bypass grafting; *IABP*, intra-aortic balloon pump; *MI*, myocardial infarction; *NYHA*, New York Heart Association; *OFF*, off-pump; *ON*, on-pump; *STS*, Society of Thoracic Surgeons. **P* values were calculated only for nonmissing data. For categoric variables, *P* values are based on chi-square rank–based group means score statistics (equivalent to Kruskal–Wallis test for row variables with 3+ levels and Wilcoxon test for 2 levels). For continuous/ordinal variables, *P* values are based on chi-square 1° of freedom rank correlation statistics. All tests treat the column variable as ordinal.

who probably perform OFF CABG in select situations, such as hostile ascending aortas or single- or double-vessel bypasses for patients with good targets. Some surgeons avoid OFF CABG altogether. Only a few cardiac surgeons and centers perform enough of these procedures to be considered ''specialists'' in OFF CABG. The decline in OFF cases was mostly driven by a decline in the use of OFF by centers or surgeons who previously used it relatively frequently (Figure 3).

One potential driver of OFF adoption during its periods of peak use might have been patient demand. However, from a patient's perspective, traditional ON and OFF CABG are perceived to be equally invasive because both are associated with a sternotomy incision. Therefore, many surgeons may have had little incentive to perform OFF CABG on a routine basis. In addition, concerns relating to graft patency and completeness of revascularization,[28] although not uniformly shared by all

surgeons, undoubtedly reduced the appeal of OFF CABG.

The overall conversion rates have fluctuated approximately 6% in recent years. There was an inverse relationship between OFF surgical volume and conversion rates. The unplanned conversion rate was 1.1% in 2004 and increased to 3.3% in 2012 (Figure E2). The increase in unplanned conversions might be due to the increasing proportion of patients with complex disease and severe comorbidities, which might predispose them to intraoperative hemodynamic scenarios that can lead to emergency conversions. Alternatively, the increase in unplanned conversions could be a manifestation of diminishing surgical and operative team experience related to the decline in OFF cases and an increase in the relative proportion of ''occasional'' OFF practitioners.

Conversion from OFF to ON CABG is generally associated with poor outcomes,[29-31] especially when done on an emergency basis.[31] Conversion rates should be monitored with the goal of identifying predisposing factors. This may permit surgeons to recognize patients who are at high risk for conversion and to take appropriate preventive measures: performing ON CABG, augmenting OFF approaches with special monitoring or interventions to reduce the risk of conversion, or establishing a lower threshold for conversion before patients are critically unstable.

Study Limitations

This STS ACSD study is limited by the retrospective nature of its design and the need to reconcile multiple STS dataset versions, which varied in terms of the data elements captured and the definitions used. Although we were able to exclude robotically assisted cases, other nonsternotomy procedures were not specified uniformly over the years in the different versions of the database. Nonsternotomy cases accounted for less than 1% of CABG cases, and their inadvertent inclusion had little effect on the study's findings. In addition, hybrid cases only began to be captured in 2011 and accounted for approximately 2% of the annual CABG cases. Although the use of hybrid procedures was not factored in and hybrid cases were not separately analyzed in our study, this is an evolving field that is worth tracking in future studies. Conversions were not captured and categorized as accurately as they would be in a prospective study. Conversely, the study's strengths derive from its use of a large, robust, and validated prospective database, so that our findings accurately represent the national trend.

CONCLUSIONS

There has been a decline in the relative use of OFF CABG in the United States. This reflects the reality that although OFF CABG offers the advantage of avoiding CPB, it is inherently a more technically difficult operation to perform, particularly for the occasional OFF operator or program. In addition, in randomized controlled trials, OFF CABG has shown no mortality or major morbidity benefit and has been associated with less frequent complete revascularization than ON CABG. However, it is undeniable that OFF is a valuable technique in the armamentarium of cardiac surgeons, and every effort should be taken to teach it to cardiac surgery trainees. OFF CABG use will probably continue to be concentrated in specialized centers with dedicated OFF surgeons and the appropriate infrastructure and resources.

The authors thank Stephen N. Palmer, PhD, ELS, for contributing to the editing of the article.

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Discussion

Dr Harold Lazar *(Boston, Mass)*. In their study, Dr Bakaeen and colleagues have documented what many of us already know: There has been a steady and significant decline in the use of OFF CABG among US surgeons. From a peak of 23% in 2002, only 17% of CABG procedures are now done OFF. Eighty-six percent of surgeons who perform OFF CABG do less than 20 cases per year, and 34% of surgeons do not do any OFF CABG procedures. The decline in OFF CABG procedures appears to be driven mostly by a decrease in high-volume centers and by high-volume surgeons.

Although Dr Bakaeen and colleagues have told us that OFF CABG is declining, they have not told us why. But from my recent review of the literature on this subject, I think I know.

Retrospective nonrandomized, prospective randomized, and multiple and meta-analyses have failed to show any significant improvement in short- or long-term morbidity and mortality with OFF CABG techniques. Even in those studies in which OFF CABG resulted in small improvements in early postoperative outcomes, these improvements were no longer apparent on long-term follow-up. Several studies suggest that long-term survival may be significantly reduced in OFF CABG cases because of incomplete revascularization with this technique, which has been associated with an increase in recurrent angina and the need for increased re-revascularization procedures.

A major impetus for performing OFF CABG was to avoid the detrimental effects of CPB. However, studies have not shown any decrease in the activation of CPB-induced inflammatory pathways or improvements in neurologic function or alterations in quality of life compared with standard ON CABG techniques.

Some have suggested, as you noted, that OFF CABG be performed only in high-volume centers by surgeons who have developed a high level of expertise with this technique. However, as noted in your presentation, it is this group of high-volume centers and surgeons that appear to be responsible for the decreased use of OFF CABG. It has been recommended that the learning curve for OFF CABG is between 50 and 75 cases. However, as the volume of CABG surgery continues to decline and the complexity of the coronary anatomy increases, it will become harder to train younger surgeons to perform OFF CABG, and I think these numbers will continue to decline.

Cardiac surgeons always have been motivated to adopt new techniques that will result in improved outcomes for their patients. The continuing decline in the use of OFF CABG by US surgeons is an indication that OFF CABG is not this type of technique. No operation that can be performed by only a select group of experienced, talented surgeons has ever achieved the test of time. CABG surgery must be able to be performed expertly under all circumstances, on all patients, at all hospitals, regardless of the cardiac volume. And these goals appear to be best achieved with ON CABG, which remains the gold standard.

I have only one question to ask you. Do you plan a follow-up study where you collect data from individual surgeons, let's say from the American Association for Thoracic Surgery or STS database, to determine exactly why they are not performing OFF CABG at this point?

Dr Bakaeen. I knew that Dr Lazar would be discussing my article, so I decided to preemptively put a slide in expecting him to ask me questions, and I thought they would be best answered using his own wise words. He eloquently stated how only an operation performed well by only a few surgeons has not stood the test of time.

With regard to conducting a follow-up study, I think that's an interesting study. I would be interested in sending out a survey asking the US surgeons why they have decreased their use of OFF CABG. We did speculate in the article and the presentation today about the possible reasons behind this decline.

A recent publication from Sweden reported that, nationally, 6% of CABGs are performed OFF. In addition, there is a similar study from the Veterans Affairs system (that does not report to the STS database) with results that exactly mirror our current findings.

Dr Alfonso Chiscano *(San Antonio, Tex)*. I have one observation and one question. The observation is that those of us trained in the late 1960s and early 1970s will find it difficult to adapt

this technique as routine. In the words of my mentor, Dr Cooley, this is like making love in a hammock, very difficult. Do you have anything in the simulation lab that we can simulate, like riding a horse, in moving all these parameters so we can train the residents safely?

Dr Bakaeen. I think it's important to train residents, and the debate has been settled. ON CABG in an average population, in an average practice, is a better operation. But in the hands of the few experts that could demonstrate similar or superior outcomes with OFF CABG, then that technique is justified on a routine basis.

Now, for the next generation, it's important to expose them to OFF CABG. Simulators are a great way to do it, but they're not quite like the real thing. So I would encourage residents to scrub with those dedicated surgeons experienced in OFF CABG or to seek out those single- or double-vessel OFF CABGs that are performed by other surgeons to gain their experience. There are always going to be some patients with certain risk profiles that would benefit from OFF CABG, including cirrhotic patients or those with diseased or porcelain aortas.

Dr Kavous Hakim-Meibodi *(Bad Oeynhausen, Germany).* Congratulations on showing the results in the United States, which are similar in Europe, especially in Germany.

We have to confront a population of ever sicker and older patients who have a low tolerance for our procedures. From our point of view, OFF CABG in this population is the answer to their problem, especially if you drive one step further and avoid manipulating the aorta.

In our group, we have demonstrated that if a high-volume center, which was formally conservative, completely ON, can be changed to an 80% OFF group, the results of the operation can be improved because mortality will be going down to less than 1%, and strokes can be reduced by up to 50%. So this is the motivation to do that.

OFF surgeries should be done as ON surgery in a team approach, and if you do it, don't spare the procedure for the catastrophic case because you'll have no team that is trained in that.

So if you want to do OFF CABG, you have to have a complete team trained in the procedure, and that's crucial for success. It's no use to perform just 20 cases because the learning curve alone and to be in training takes up to 50 cases per year per the individual team. So you have to be on that team with your complete group to be successful in OFF surgery.

Dr Bakaeen. The German Off-Pump Coronary Artery Bypass Grafting in Elderly Patients study looked at OFF versus ON CABG in German patients aged more than 75 years in the hands of experienced surgeons and demonstrated no difference in outcome. So I'm glad that in your hands you have better outcomes with OFF CABG, and I recommend that you continue adopting and using this technique. My view on this is that we should tailor the operation to the patient and not the patient to the operation.

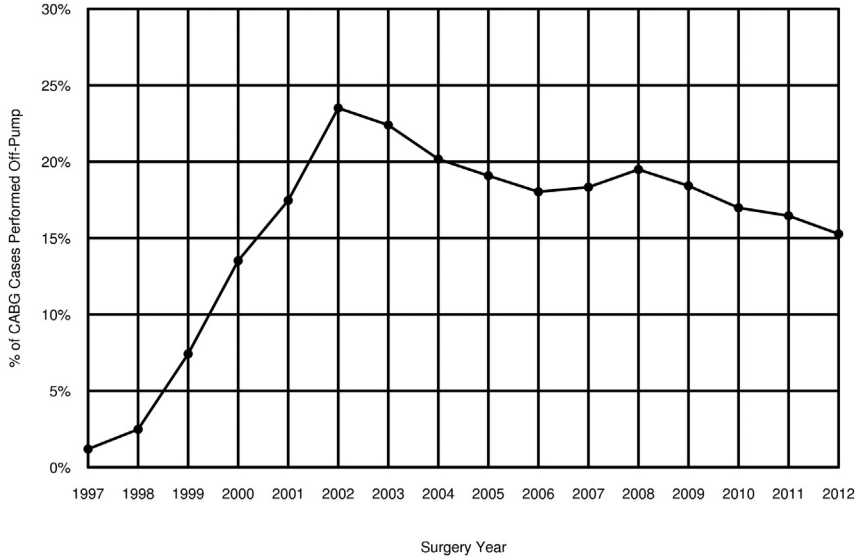

FIGURE E1. Relative use of ON versus OFF CABG for subgroup A: centers that submitted data for the entire study period (1997-2012). *CABG*, Coronary artery bypass grafting.

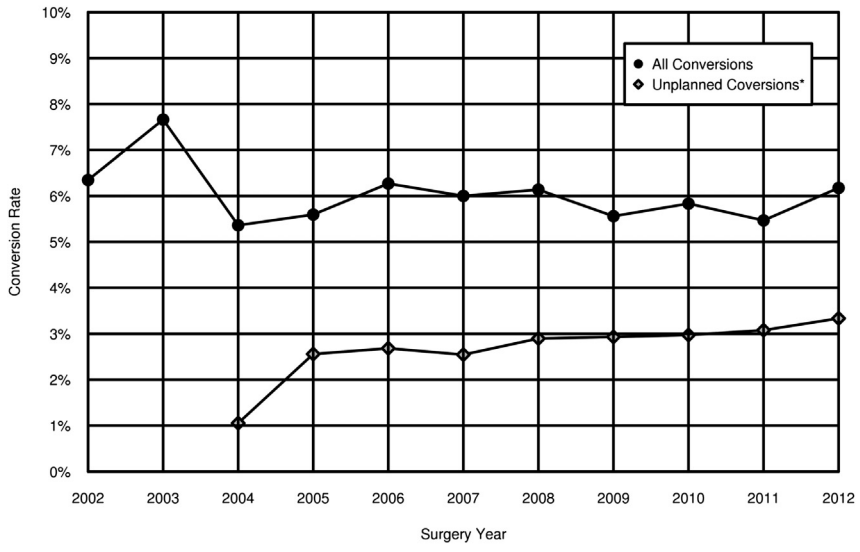

FIGURE E2. Conversion rates between OFF and ON among cases started OFF.